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Dynamics and Structure of Planetary Rings

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Our recent research efforts have been directed towards sharpening our view of the kinematical and dynamical properties of the Uranian rings, with the combination of Earth-based and Voyager observations, and in obtaining and interpreting new observations of the Saturn system from the remarkable stellar occultation of 3 July 1989. Some of the highlights of these studies are:

- *Detailed comparison of structure and dynamics of the Uranus rings* from joint analysis of high quality Earth-based data and the complete set of Voyager occultation measurements. A major task during this past year has been the completion of a comparative survey of the structure and dynamics of the Uranian rings, using all available high quality stellar occultation observations and the complete set of Voyager 2 ring occultation measurements. These have been published in a chapter (French *et al.*, 1990) of the University of Arizona's volume, *Uranus*. Much of the material in this chapter is new work supported by this grant. We have devoted considerable attention to a careful and self-consistent determination of ring widths and integrated optical depths (Tables V–VIII and Figures 7–10), and to quantifying the forced apsidal precession due to J_6, the small shepherd satellites, and the more distant classical Uranian satellites (Figure 6).
- *Comprehensive search for weak normal modes excited in the Uranian rings*, analogous to the m=2 and m=0 normal modes previously identified for the δ and γ rings. During the past year, we have searched for any low wavenumber (m=0 to 10) normal modes (both prograde and retrograde) that might significantly lower the post-fit radius residuals. Our goal is to detect additional excited normal modes, or to place quantitative limits on their amplitudes, for all nine of the classical narrow Uranian rings. Our complete survey has revealed *no additional normal modes for any of the rings*, for amplitudes larger than about 0.5 km. At the same time, there are provocative hints of smaller-amplitude modes for some of the rings. From our complete survey of all the rings and all normal modes from m=0 – 10, we have found no *definitive* evidence of excited normal modes in any rings (other than γ and δ) with an amplitude of 0.5 km or larger. At the same time, we have found provocative hints of possible normal modes in a number of rings:

Table I

Ring 6	m=0
Ring 5	m=0
Ring α	m=2 (prograde)
Ring η	m=2 (prograde)

Conclusive identification is hampered by undersampling at the higher wavenumber modes, and before we publish these results, we would like to include the additional data points to be obtained from two high-quality stellar occultations we have been awarded time to observe from the IRTF during June, 1991.

- *An on-going search for faint rings and ring arcs of Uranus*, using both Voyager images of the rings and Earth-based and spacecraft stellar occultation data. In collaboration with Mark Showalter of NASA/Ames, we have begun a study of the Uranian rings using the Voyager images. A new technique for finding and characterizing some of the faintest ring material is providing what amounts to a brand new look at this ring system. In the past, Showalter has pioneered the use of systematic pixel averaging to improve the signal-to-noise ratio of faint ring material in Voyager images. We are now exploring the logical extension of this technique, in which we use the same process to combine results from multiple images. Our best profile of the Uranian ring system generated in this manner represents a sum of 25 of the highest resolution Voyager images taken in backscattered light. Since each frame is a 15.36 second exposure, this is the equivalent of a profile generated from a single frame exposed for 384 seconds. Each 10 km radial bin in the profile contains an average of 10,000–20,000 pixels, making features visible that are no brighter than a few hundredths of a raw pixel DN, or "data number." The new profile reveals the faintest ring structures between the nine "blades of grass" that are the traditionally identified Uranian rings. The λ ring at 50,000 km is clearly visible, as are several more marginal features scattered among the major rings. One can also see a faint outward extension to ring 4, and perhaps an inward extension to ring η.
- *Comparison of upper stratospheric temperatures of Uranus* inferred from Voyager ultraviolet occultations with results of ground-based occultation observations. Earth-based stellar occultations by Uranus have been used to determine the temperature structure of the Uranian upper atmosphere near the 1 μbar level. Traditional analysis methods, using inversion of the light curves and isothermal model fits to the data, have been in good accord, giving stratospheric temperatures of about 150K for most occultations, and in all cases below 200K. In contrast, Voyager UVS stellar and solar occultation observations have been interpreted as showing temperatures as high as 500-700K in the region just above the 1 μbar level. These results seem inconsistent at first glance, and in order to connect the two adjacent sets of observations, Herbert *et al.* (1987, 1988) proposed that there is a very large temperature gradient (several hundred K per scale height) between the 3.3 and 0.5 μbar levels. The energy budget of the upper stratosphere would clearly be strongly influenced by such large local temperature changes. We have now demonstrated that, in spite of the apparent incompatibility,

Herbert *et al.*'s thermal model for the Uranian stratosphere is indeed consistent with the Earth-based observations.

- *Observations of the 3 July 1989 Saturn occultation of 28 Sgr* at four visible wavelengths and at 2.1 μm, resulting in a complete ingress and egress scans of the ring system, atmospheric immersion and emersion light curves, and definitive observations of Saturn's central flash, including detection of multiple virtual stellar images around the limb of the planet. Much of our effort over the past year has been devoted to the reduction and analysis of the IR imaging data. The analysis is complicated by the presence of significant scattered sunlight from the rings at 2.1 μm, and we have developed sub-pixel image shifting and template subtraction algorithms to process the more than 40,000 individual images to obtain a high SNR light curve of the ingress and egress ring and atmosphere occultations. These observations also provided direct detection of multiple virtual stellar images along Saturn's limb during the 'central flash' portion of the occultation, when the star was behind the center of Saturn's disk as seen from the Earth. Although we are still in the process of obtaining our definitive normalized and calibrated light curve, we have used preliminary results to determine occultation timings of ring edges and sharp features, the projected diameter of the occulted star, astrometric fits to the Saturn system geometry, temperature profiles of Saturn's stratosphere, and models of Saturn's central flash, taking account of the effects of ring opacity. We have also developed color-correction algorithms to extract the occultation signal from the multi-channel visible wavelength observations.

References

R. G. French, P. D. Nicholson, C. C. Porco, and E. A. Marouf (1990) "Dynamics and Structure of the Uranian Rings." A chapter in *Uranus*, U. of Arizona (Bergstralh and Miner, eds.)

Herbert, F., B. R. Sandel, R. V. Yelle, J. B. Holberg, A. L. Broadfoot, D. E. Shemansky, S. K. Atreya, and P. N. Romani (1987). The upper atmosphere of Uranus: EUV occultations observed from Voyager 2. *J. Geophys. Res.* **92,** 15093-15109.

Herbert, F. (1988). Heat sources in the thermosphere of Uranus. *B.A.A.S.* **20,** 822.